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ECONOMICS OF REGIONALIZATION: An Overview

A Report of the Subcommittee on Economics and Regionalization of the Committee on Water Supply Resources Planning and Management of the Environmental Engineering Division of the American Society of Civil Engineers

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16. ABSTRACT

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Passage of the Safe Drinking Water Act of 1974 (PL 93-523) emphasizes the need for water supply professionals to seriously consider regionalization issues. The Act which requires the U.S. Environmental Protection Agency (EPA) and State agencies to develop and enforce water quality standards, will have a significant impact on the ways in which purveyors view their responsibility for supplying treated water to the consumer. One of the consequences of the Act has been an emphasis on the possible benefits of consolidating water supplies into regional systems to offset some of the possible regulatory cost increases through scale economies and other gains in economic efficiency. This report investigates some of the arguments for and against regionalization of systems in the water supply industry. The history, potential advantages, disadvantages and costs and benefits or regionalization are examined.

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ECONOMICS OF REGIONALIZATION: AN OVERVIEW

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Abstract

Regionalization is often suggested as a means of solving a large number of water supply problems. Unfortunately the word regionalization has many different meanings. Among other meanings, it can be a coordinated approach between independently owned and managed organizations or a single institution that has sole responsibility for water supply over a large area. Finding a universally applicable definition for regionalization is difficult.

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The report concludes that regional systems have many advantages, including lower unit costs and a tendency towards better and more consistent water quality. However the benefits of regional systems are not unlimited. Adoption of the regional concept should only be done if a full understanding of the positive and negative aspects have been considered.

KEY WORDS: ECONOMIC ANALYSES; MANAGEMENT; PLANNING; REGIONAL PLANNING; SYSTEMS ENGINEERING; WATER SUPPLY; WATER DISTRIBUTION

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ECONOMICS OF REGIONALIZATION: AN OVERVIEW

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Introduction

A solution often suggested for solving a large number of Water Supply problems is that of regionalization. Unfortunately regionalization has many different meanings. Regionalization can refer to a single organization that has sole responsibility for the management and operation of a water supply system over a large area, or it can be a coordinated approach between several independently owned and managed organizations providing service to a region. Regionalization can also mean the coordination of several services or functions of government under a single policy making board to serve independent water systems. Finding a universally applicable definition for regionalization is difficult.

The American Water Works Association formed a special committee to assist in finding a definition of regionalization for water utilities, but was unable to agree unanimously on a single definition and finally settled on a composite of several viewpoints.[1] Their final definition of regionalization was as follows: Regionalization of a water system is (1) a creation of an appropriate management or contractural administrative organization, or (2) a coordinated physical system plan of two or more community water systems in a geographical area for the purposes of utilizing common resources and facilities to the optimum advantage in planning, designing, constructing, operating, and maintaining water supply systems that meet current minimum standards.

Passage of the Safe Drinking Water Act of 1974 (PL 93-523) emphasizes the need for water supply professionals to seriously consider regionalization issues.[2] The Act which requires the U. S. Environmental Protection Agency (EPA) and State agencies to develop and enforce water quality standards, will have a significant impact on the ways in which purveyors view their responsibility for supplying treated water to the consumer. One of the consequences of the Act has been an emphasis on the possible benefits of consolidating water supplies into regional systems to offset some of the the possible regulatory cost increases through scale economics and other gains in economic efficiency. This paper investigates some of the arguments for and against regionalization of systems in the water supply industry. The history, potential advantages, disadvantages and costs and benefits of regionalization are examined.

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Status of Water Supply in the United States

The following tables provide insight into the status of water supply in the U.S. Table 1 shows water use in 1965 with projected requirements for withdrawals and consumptive use through 2020.[16] Municipal water supply which represents the second largest consumptive use is projected at 157 billion gallons per day by 2020. This value compared with an estimated 1,200 billion gallons per day of average annual surface fresh water supply would indicate there should be few problems in supplying all types of demand.

In the past, sources of water supply were relatively easy to find. Now most of these easy to access sources have been committed and used to their fullest extent resulting in extensive capital outlays for acquisition and transportation of water from more difficult to reach sources. Reaching out to these sources may also require crossing jurisdictional boundaries, resulting in interregional water transfers.

When the uneven geographic distribution of supply and demand is considered as well as the increasing deterioration in source quality, the slack in supply above demand is tighter than might seem on first examination. The distribution of system size is also uneven as shown by Table 2.[3] Forty-four percent of the population served by community supplies is served by less than 1% of the systems. In 1970, 75% of the U.S. population lived in 212 Standard Metropolitan Statistical Areas (SMSA), and a third of the U.S. population resided in the 24 largest metropolitan areas. These data illustrate the concentration of large demands for water supply in relatively small geographic areas. However, even with this concentration effect, future demands can probably be met if water resources are effectively managed. But, satisfying this demand will no doubt result in increasing monetary costs and political problems regarding water transfer and regional management.[16]

Deteriorating water quality in some new and existing sources plays a complex role in urban water supply systems. More rigorous standards for treated water are being asked for, as reflected in the 1974, Safe Drinking Water Act. These new quality standards will no doubt have an adverse impact on small utilities and in some cases require the installtion of expensive and/or technically infeasible treatment techniques.[2,7] A possible future trend in urban water supply may be towards the crossing of political boundaries to find available sources of water and a consolidation of water utilities to form regional systems. For example, a recent study of treated water supplies in northwestern New Jersey concluded that a century of evolution in this field has resulted in many separate systems characterized by lack of long-range planning, and piece-meal and inequitable arrangements for solving local differences in supply and demand, incomplete projects and the need for state intervention during emergencies to break institutional logjams.[11] One solution proposed is that of regional management of water systems.

TABLE 1

ESTIMATED WATER USE AND PROJECT REQUIREMENTS, BY PURPOSE, IN THE UNITED STATES

(Million Gallons Daily)*

Type of Use	Used 1965	Projected Withdrawal Requirements 1980	2000	2020	Used 1965	Projected Consumptive Use Requirements 1980	2000	2020
Rural domestic	2,351	2,474	2,852	3,334	1,636	1,792	2,102	2,481
Municipal (public supplied)	23,745	33,596	50,724	74,256	5,244	10,581	16,478	24,643
Industrial (self supplied)	46,405	75,026	127,365	210,767	3,764	6,126	10,011	15,619
Steam-electric power:								
Fresh	62,738	133,963	259,208	410,553	659	1,685	4,552	8,002
Saline	21,800	59,340	211,240	503,540	157	498	2,022	5,183
Agriculture:								
Irrigation	110,852	135,862	149,824	160,978	64,696	81,559	89,966	96,919
Livestock	1,726	2,375	3,397	4,660	1,626	2,177	3,077	4,238
Total	269,617	442,626	804,610	1,368,088	77,782	104,418	128,205	157,085

* 1 mgd = 3,800 m^3/day.

Source: Koelzer, P. E. and Bigler, A. B., Policies and Organizations for Urban Water Management

TABLE 2

DISTRIBUTION OF COMMUNITY WATER SYSTEMS

Systems Size, in Persons Served	Number of Water Systems	Percentage of Total Systems	Total Population Served (10^3)	Percentage of Total Population Served
25 to 99	7,008	18	420	0.2
100 to 9,999	30,150	75	36,816	20.8
10,000 to 99,999	2,599	6	61,423	34.6
100,000 and over	243	1	78,800	44.4
Total	40,000	100.0	117,459	100.0

Source: Clark, R. M., "Water Supply Regionalization: A Critical Evaluation", ASCE

Drinking Water Quality

One of the most compelling arguments for the development of regional water supply systems is the relationship existing between the quality of drinking water and size of system. A Community Water Supply Survey was initiated by the Bureau of Water Hygiene of the U. S. Public Health Service (USPHS) in February 1969 to determine if the American consumer's drinking water met with USPHS drinking water standards, which were, at that time, the closest thing to National drinking water standards in existence.[19] The survey was designed to give an assessment of drinking water quality, water supply systems, and surveillance programs in urban and suburban areas in each of the Department of Health, Education and Welfare's nine regions. With the exception of Region I (where the entire state of Vermont was included) a whole Standard Metropolitan Statistical Area (SMSA) was the basis for each survey. Evaluations were made on all water supplies within a given SMSA, thereby allowing an assessment of the drinking water quality of the large central city, the suburbs, and the smaller communities located in the counties in the SMSA, and the interaction among them.

Such an analysis provides a natural basis for regional evaluation and one of the major conclusions drawn in this regard supports the need for the consolidation of regional water supply systems. A major finding of the study was that small communities or systems had more water quality problems and facility deficiencies than large ones, making consolidation or regionalization of some systems advisable. A conclusion by the principle investigators was that their merger would seem feasible where institutional arrangements permit. Merging these systems would reduce costs and improve the quality of the water delivered. It was recommended, therefore, that regionalization be encouraged.

Table 3 reports the results of the survey. According to the table smaller systems (500 or fewer people served) present significantly greater problems than do larger systems. It can be seen from Table 3 that in all categories small systems fail to meet recommended standards. The conclusion that smaller systems with major operational problems be merged with larger systems that exhibit fewer problems seems justified.

The article by McCabe, et al., clearly suggests that improved water quality may result from regionalization.[19] This improvement can be translated into fewer water-borne disease outbreaks and reduced costs for health department surveillance.

Reliability in supply quantities should also be greater for bigger systems, since regularization reservoirs are often part of larger systems, and most large systems have some degree of redundancy.[25] If a system has multiple sources reliability of supply will increase, assuming statistical independence between sources. In a later section a discussion will be presented relating drinking water quality, cost, and system size. Obviously cost and economics enter these issues of reliability and quality to a significant degree.

TABLE 3.

SUMMARY OF RESULTS OF COMMUNITY WATER SUPPLY SURVEY BY CATEGORY AS A PERCENTAGE

Item	Number of Systems	500 or less	500-100,000	Greater than 100,000	All Populations
		446	501	22	969
Water quality evaluation	Met drinking water standards	50	67	73	59
	Exceeded recommended limits	26	22	27	25
	Exceeded mandatory limits	24	11	0	16
	Survey population in each group in thousands	88	4,552	14,463	18,203
Facility deficiencies	No major deficiencies	39	47	64	44
	some major deficiencies	61	53	36	56
Bacterio-logical survillenace	Met criteria	4	15	36	10
	Did not meet criteria	95	85	64	90

SOURCE: McCabe, E. J., et. al, Survey of Community Water Supply Systems, JAWWA.

Economic Characterization of Water Supply

A prevailing characteristic of water supply technology is the effect of economies of scale (increasing unit costs with decreasing system size). In an early study revealing this phenomenon, Orlob and Lindorf examined treatment cost to determine its relationship to the cost of surface water transportation, reclaimation of wastewaters, ground-water recharge, and any other alternatives available for increasing water supply in California.[23] Construction cost was theorized as a function of the explanatory variable, design capacity, as follows:

$$C_c = aQ_n^b \qquad (1)$$

in which C_c = total capital cost of a complete water treatment facility in thousands of dollars; Q_n = design capacity of the plant, in millions of gallons per day (mgd); and a,b = constants. Statistical estimation of the equation parameters generated the following relationship:

$$C_c = 257\ Q_n^{0.67} \qquad (2)$$

The value of b = 0.67 implies that economies of scale may exist in treatment plant construction. Dividing both sides of equation (2) by Q_n yields:

$$C_c/Q_n = 257\ Q_n^{-0.33} \qquad (3)$$

The term C_c/Q_n is the unit cost of capacity and the exponent of Q_n is less than 0. According to equation 3 unit cost therefore decreases with increasing Q_n or capacity, illustrating "economies of scale". Similar relationships have been observed for operating and maintenance costs.[1] Figure 1 is a plot of equation (3) and tangents l_1, l_2, l_3 illustrate the difference in slopes of various curve segments. Note that the slopes change dramatically in the ranges >0-2.5 mgd (9500 m^3/day), 2.5 mgd - 20 mgd (76,000 m^3/day), and >20 mgd (76,000 m^3/day). For example, the slope of equation 3 is given by its first differential with respect to Q_n as follows:

$$\frac{\partial (C_c/Q_n)}{\partial Q_n} = -84.8\ Q_n^{-1.33} \qquad (4)$$

Table 4 contains values for the right-hand side of equation (4) at selected points.

As can be seen from Table 4 and Figure 1, significant differences exist in the slopes of the various curve segments. One might therefore define a "small" system as one with a high unit cost or, equivalently, one with a capacity that puts it within the segment of the cost curve having the maximum slope. Such a system would have a capacity of 2.5 mgd (9500 m^3/day), or less. Following this convention a system having approximately 2.5 mgd (9500 m^3/day capacity), but less than 20 mgd (76,000 m^3/day) is transitional and those systems of 20 mgd (76,000 m^3/day) or greater are large.

TABLE 4

SLOPES OF EQUATION 4

Q_n (mgd)	Value
0.5	-213.3
5.0	-10.0
50.0	-0.5

SOURCE: Clark, Robert M., "Small Water Systems: Role of Technology" ASCE

NOTE: 1 mgd = 3,800 m^3/day

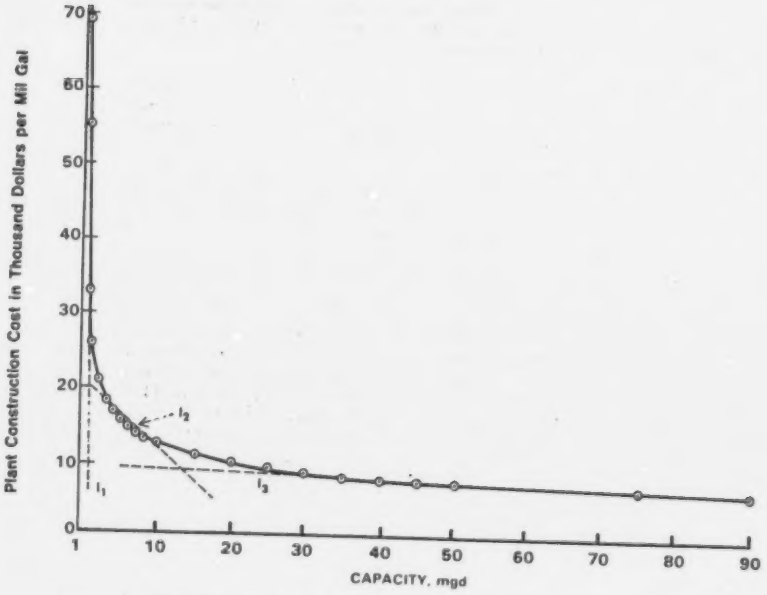

FIGURE 1. UNIT COST CURVE FOR WATER TREATMENT TECHNOLOGY.

Recent studies confirm these effects. Figure 2 shows the results from a detailed study of expenditure patterns over 10 years for 12 water utilities geographically scattered across the United States.[4] Both total supply cost and total treatment cost are shown.

Table 5 summarizes data collected on both large and small systems (1974 costs). As can be seen, the cost of 12 large water supplies averaging approximately 85 mgd (32,300 m^3/day) is 42¢/1,000 gal (10.9 ¢/m^3). The average cost for 30 small supplies averaging approximately 1.7 mgd (6460 m^3/day) is 85¢/1,000 gal (22.1 ¢/m^3). Unit costs for the small systems are uniformly higher in all of the cost categories.

Cost and Quality of Water

The impact of size, quality and system cost are extremely important as far as drinking water is concerned. Using data taken from the Community Water Supply Survey an analysis was made to evaluate these factors. Data from the Cincinnati SMSA was used to evaluate the cost of water supply with respect to water-quality and system factors and to analyze the economic impact of cost, price and quantity of water consumed.

The Cincinnati SMSA

The Cincinnati SMSA includes six counties in three states. Data were selected as a part of this survey on 67 public water suppliers, including 57 that piped water to homes and ten that served institutions, trailer parks and water haulers. Twenty-two of these community water supplies were analyzed in an attempt to relate those factors which might be assumed to affect the price that the consumer pays for water.[5] Table 6 contains data on the costs, quality and system information for each of the 22 community water supplies which were analyzed.[17]

None of the supplies had their water rated as unfit to drink. The price paid for the water by the consumers for the first consumptive block, in Column 8 was used since the majority of the water consumption is for domestic purposes and therefore, falls in the first rate block. The quality ratings and quantity information were based on the 1969 survey (CWSS) and the population, population density and per capita income data were taken from the 1970 U.S. census.

Economic Analysis

Two approaches were used in the analysis of the data shown in Table 6.

The first approach was to use regression analysis to relate the price of water, to such factors as population density, total water demand, and the quality rating of the utility.[10] The second approach relates the price of water to the consumer to consumption.

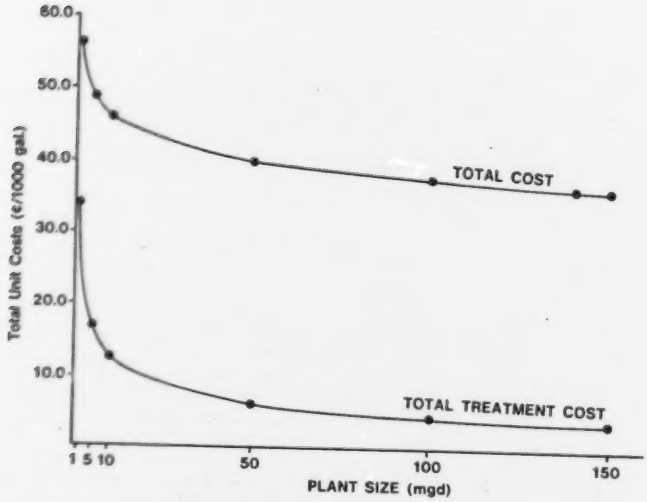

FIGURE 2. TOTAL UNIT COSTS FOR WATER SUPPLY SYSTEMS AND TREATMENT.

TABLE 5. COSTS FOR LARGE AND SMALL WATER SUPPLIES BY FUNCTION (1974)

IN CENTS PER 1,000 GAL

Utility Size (1)	Revenue producing water, in millions of gallons per day (2)	Support Services (3)	Acquisition (4)	Treatment (5)	Distribution (6)	Interest (7)	Total (8)
Large	86*	9.9	5.4	4.8	12.7	8.7	41.5
Small	1.7[b]	15.0	12.4	8.8	35.3	12.9	85.4

*Average of 12 systems
[b]Average of 23 systems
1 mgd = 3,800 m^3/day; 1¢/1,000 gal, = 0.26¢/m^3

SOURCE: Clark, R. M. et. al., The Cost of Water Supply and Utility Management.

TABLE 6

QUALITY, QUANTITY AND COST INFORMATION FOR 22 WATER SUPPLIES IN CINCINNATI SMSA

Area	Population Served	Population Density People/ sq/mi	Average Daily Demand mgd	Supplier of Water*	Source of Water**	Quality Indicators† Q_1	Quality Indicators† Q_2	Base Price $/1000 gal.	Per Capita Income $	Average Daily Per Capita Demand gpcd
1	850,000	6,569.3	112.60	1	1	1	1	0.35	3141	132
2	11,000	4,166.8	1.50	1	0	1	0	0.45	2813	136
3	4,526	255.0	1.80	1	0	1	1	0.65	10,268	120
4	31,000	11,526.7	4.00	0	1	1	1	0.30	3148	129
5	15,000	4,752.6	1.85	1	0	1	0	0.40	3171	123
6	44,000	3,942.0	2.43	0	1	1	1	0.70	2796	55
7	64,000	10,062.7	5.46	1	1	1	0	0.90	2476	85
8	15,000	2,012.8	0.75	0	1	1	1	1.30	3441	50
9	30,070	10,739.3	3.39	1	1	1	1	0.75	2307	97
10	5,140	4,308.9	0.36	1	0	1	0	0.70	2902	71
11	6,500	4,308.9	1.05	1	0	0	0	0.30	3098	162
12	5,000	2,276.4	0.57	1	0	1	0	0.50	2925	76
13	6,200	1,524.8	0.25	1	0	1	1	1.15	3159	40
14	10,000	2,865.2	0.90	1	0	1	1	0.80	5974	90
15	6,300	168.7	0.52	1	0	1	0	0.85	2710	82
16	5,200	2,382.9	0.25	1	0	1	0	0.80	2639	48
17	6,010	8,904.3	0.34	0	1	1	0	0.40	2590	55
18	3,000	1,660.6	0.30	1	0	1	0	0.70	4778	100
19	4,530	4,131.0	0.44	1	0	1	0	0.55	3296	97
20	2,720	4,533.3	0.32	1	0	0	0	0.20	2544	188
21	2,200	1,656.2	0.10	1	1	1	0	1.15	3543	45
22	4,000	2,909.2	0.13	0	1	1	1	0.70	4225	32

1 sq mi = 2.59 km^2; 1 mgd = 3,800 m^3/day; 1¢/1,000 gal = 0.26 ¢/m^3; 1 gpcd = 3.785 L pdd

SOURCE: Haddox, Franklin D., Water Supply and Consumer Costs

Cost of Water vs System Factors

Regression analysis was used to relate various factors including quality to the cost of water.[5] The variables used in the analysis are given below:

C = the price in dollars per 1000 gal of water

P = the population served by the water utility

PD = the population density in persons per square mile for the service area

D = average daily demand for water in millions of gallons

SW = supplier of water, where SW = 1 implies that the utility is the primary supplier of water (acquires, treats and distributes water) and SW = 0 implies that the utility is a secondary supplier (purchases and distributes water)

SO = source of the water utility supplies, where SO = 1 implies that the utility uses surface water, and SO = 0 implies that the utility uses ground water

Q_1 and Q_2 = dummy variables indicating the rating of the water utility where $Q_1 = 1$, $Q_2 = 1$ implies a rating of good; $Q_1 = 1$, $Q_2 = 0$ implies that the rating is fair; and $Q_1 = 0$, $Q_2 = 0$ implies that the rating is poor.

Using a step-wise regression analysis, the following equation was obtained:

$$C = 0.00000944\ P - 0.000005972\ PD - 0.07722744\ D + 0.42094866\ SW + 0.47268092\ SO + 0.26372458\ Q_1 + 0.15042853\ Q_2 + 0.102490 \quad (r = 0.81) \qquad (5)$$

The multiple correlation coefficient for equation (5) is approximately 0.81, which means that nearly 66 per cent of the variation in the dependent variable is explained by this equation. This analysis shows that such variables as population density, whether or not the utility is a secondary or primary supplier, the source of water, total population served, total demand, and rating of the utility play an important role in the cost of water.

In equation (5) as population density increases, price per 1000 gal decreases proportionally, a finding that is consistent with those of other investigators.[23] As might be expected, the price of water is influenced by the source of water. Surface supplies are more expensive, no doubt, because of the storage required. One of the most interesting findings from this analysis is that secondary suppliers may charge less for water than the utilities from which they purchase. This practice appears to be contrary to common sense until one examines the fact that large users of water commonly receive discounts, and such is

apparently the case in this analysis. The large customers that buy water from this utility pay less per unit for their water than smaller consumers or individuals. In this case, the secondary suppliers then pass this discount along to their customers. The negative coefficient of the demand variable D indicates slight economies of scale with increases in total water demand.

It can be seen from Table 6 that the increases in cost because of increases in quality are significant. For example, supplier 11 in Table 6 charged \$0.30/ 1000 gal (7.8 ¢/m^3) for water but had the lowest quality rating. Upgrading this water from poor to fair ($Q_1 = 1$, $Q_2 = 0$) according to equation 5 would add an additional \$0.26/1000 gal (0.07 ¢/m^3) in cost to the existing price. Upgrading from fair to good ($Q_1 = 1$, $Q_2 = 1$) would add an additional \$0.15/1000 gal (3.9 ¢/m^3). The increase in price, therefore, because of increasing the rating of Supplier 11 from poor to good would be \$0.41/1000 gal (0.11 ¢/m^3), resulting in a total cost to the consumers served of \$0.71/1000 gal (0.18 ¢/m^3). This comparison gives a clear indication of the impact that the Safe Drinking Water Act will have on smaller suppliers.

Cost for Meeting Drinking Water Standards

An obvious solution for providing high quality drinking water would be to install appropriate technology to assure that the finished drinking water will meet the standards. The addition of new technology may substantially raise the cost of the product to the consumer, causing potentially severe economic impacts on those small systems forced to make large investments to meet the standards. In order to provide some concrete information concerning adverse impacts, a study of 23 selected small water supply systems in Environmental Protection Agency (EPA) Regions III, V, and VI was conducted.[1]

Cost data and raw and finished water quality samples were taken at each of the small utilities visited in the survey. A complete inorganic chemical profile was developed and a comparative analysis of treatment removal efficiencies was made for each system. In some cases the existing treatment plant was failing to adequately remove constituents from the raw water causing the utility to fail to meet the Safe Drinking Water Act, Maximum Contaminant Levels (MCL).[24] After examining the complete spectrum of chemical determinations for the raw and finished samples from each utility a decision was made as to whether or not a new treatment technology could be added so that finished water quality would meet existing MCLs.[21] Cost estimates were made for the proposed technology at each affected utility. For example, in Region III, one utility was identified as having a nitrate removal problem. After examining data from the raw and finished samples a hypothetical ion exchange system was assumed. Table 7 summarizes the cost calculation for an ion exchange unit to solve the utilities nitrate removal problems.

TABLE 7. COST ESTIMATES OF NITRATE REMOVAL BY ION EXCHANGE

Item (1)	Quality (2)
Flow treated, in millions of gallons per day	0.11 (418 m^3/day)
Capital cost, in dollars Construction cost	79,909
Site work	3,745
Engineering	8,809
Land	0
Legal, fiscal, administration	3,823
Interim during construction	1,131
Total	101,858
Amortized capital - 7%, 20 yr in dollars per year	9,615
Operating and maintenance cost in dollars per year	
Building and process energy at ¢/kW-hr	465
Maintenance material	2,798
Labor at 10$/hr	11,010
Chemicals[a]	6,801
Total annual operating and maintenance cost, in dollars per year	21,774
Total annual cost, in dollars per year	30,689

[a]Regenerant at $28.00/ton
NOTE: 1 mgd = 3,800 m^3/day

SOURCE: Clark, R. M., "Small Water Systems: Role of Technology" ASCE

TABLE 8. UTILITIES SELECTED FOR COST IMPACT ANALYSIS

Region	Utility	Quality Problems	Hypothesized Treatment
III	1	Nitrate	Ion exchange
V	1	Manganese	Chemical oxidation; ozone
	2	Barium	Zeolite; lime softening
	3	Barium	Zeolite; lime softening
	4	Barium	Zeolite; lime softening
VI	1	Total dissolved and fluorides	Activated alumina; reverse osmosis

SOURCE: Clark, R. M., "Small Water Systems: Role of Technology", ASCE

In a similar manner, cost estimates were developed for add-on technologies in the utilities identified as having problems.[13] Table 8 shows utility designation, the region, the quality problem for each impacted utility, and the types of treatment hypothesized for solution. Six utilities in all were identified as having water quality problems.[27]

Using the approach outlined in Table 7 cost estimates were made for each add-on technology. This cost impact analysis is hypothetical, and as can be seen from Table 9, more than one type of treatment may be applied to solve the same problem. But, depending on size, the costs associated with each technology can be very different. To properly select a treatment system for any utility requires more extensive design considerations than is possible here, and should include pilot testing. This analysis does provide, however, some realistic estimates of the costs that a small system might incur in attempting to meet the Safe Drinking Water Act requirements. Although current interest has centered on the costs associated with applying treatment technology for the removal of trihalomethanes and synthetic organics, the cost of meeting the existing interim standards in some small utilities may be high.

The solid line in Figure 3 shows the average unit costs for all of the utilities studied over the 10 year time span. The average unit cost for meeting the standards for all of the utilities is shown by a dotted line in year 10. For the entire sample, the cost is increased by less that 5% but, as shown by Table 9, cost increases for individual utilities may be significant.

The Regional Concept and Cost Minimization

Increasing quality requirements and associated increases in costs will no doubt increase interest in the regional concept particularly among small systems. Figure 4 illustrates the cost issues associated with regionalization. The lower curve represents the original cost curve for the utility, and the higher curve illustrates the cost of water supply after new treatment is installed. In order to maintain a constant cost of supply an obvious tactic is to increase the amount of water supplied. The most effective way to increase supply and drive down cost would be to move toward a regional system. It is obvious therefore that increased costs whether they are associated with regulations or not will tend to force consideration of regionalization.[27]

The AWWA committee on regionalization has listed a number of benefits and problems associated with regionalization. These items are detailed in the following sections.[26]

Benefits from Regionalization

Regionalization will facilitate improved and unified management of water systems by providing for more comprehensive supervision and better day-today direction of operations. According to the AWWA committee regionalization will enhance:

Table 9. ESTIMATED ECONOMIC IMPACTS FOR SMALL SYSTEMS

Item	Utility III-1 (2)	Utility V-1 (3)	Utility V-1 (4)	Utility V-2 (5)	Utility V-2 (6)	Utility V-3 (7)	Utility V-3 (8)	Utility V-4 (9)	Utility V-4 (10)	Utility V-5 (11)	Utility V-5 (12)
Water treated, in millions of gallons per day	0.13	1.17	-	0.41	-	0.45	-	0.0666	-	-	-
Revenue-producing water, in millions of gallons per day	0.11	0.67	-	0.27	-	0.34	-	0.055	-	-	-
Proposed treatment technique	Ion Exchange (nitrate removal)	Chemical oxidation	Ozonation	Ion Exchange Softening	Lime Softening	Ion Exchange Softening	Lime Softening	Ion Exchange Softening	Lime Softening	Activated Alumina	Reverse Osmosis
Construction cost for proposed treatment, in dollars	111,858	5,913	71,744	137,000	622,152	141,512	643,792	86,518	368,816	180,722	1,129,902
Amortized capital cost for proposed treatment (7% $\geq$ 20 yr), in dollars	9,615	559	6,773	12,934	58,727	13,358	60,769	8,167	34,814	17,057	106,655
Annual operations and maintenance cost for proposed treatment, in dollars	21,074	2,528	7,136	28,547	80,268	30,094	83,462	12,612	47,170	24,937	204,412
Total annual cost for proposed treatment, in dollars	30,689	3,087	13,909	41,481	139,355	43,452	144,231	20,779	83,984	41,994	311,065
Current annual total cost for water supply, in dollars	16,559	299,387	299,387	69,328	69,328	46,470	46,470	13,078	13,078	231,006	231,006
Project annual total cost for water supply (with proposed treatment), in dollars	47,248	302,474	313,296	110,809	208,683	89,922	190,701	33,857	97,062	273,000	542,073
Current unit cost for water supply in cents per 1,000 gallons	41.2	122.4	121.2	70.3	70.3	37.4	37.4	65.1	65.1	81.1	81.1
Projected new unit cost for water supply (with proposed treatment, in cents per 1,000 gallons	111.7	123.7	128.1	112.4	211.8	72.5	153.7	168.7	483.5	95.9	190.4

NOTE: 1 mgd = 3,800 m^3/day; 1¢/1,000 gal = 0.26¢/m^3

SOURCE: Clark, R. M., "Small Water Systems: Role of Technology" ASCE

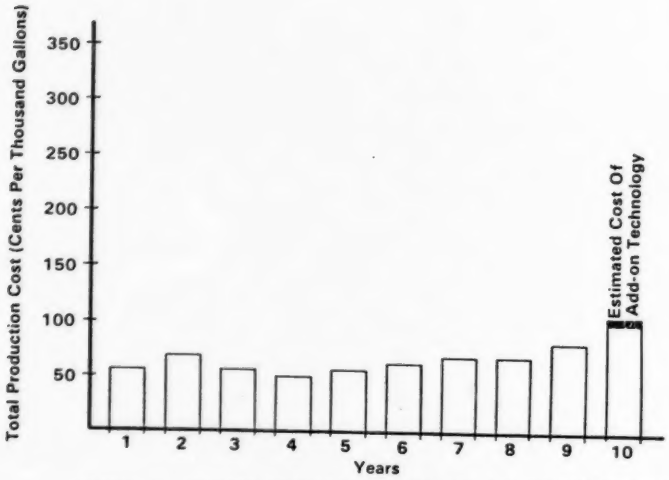

FIGURE 3. AVERAGE PRODUCTION COST FOR ALL UTILITIES WITH ESTIMATED COST OF ADD-ON TECHNOLOGY.

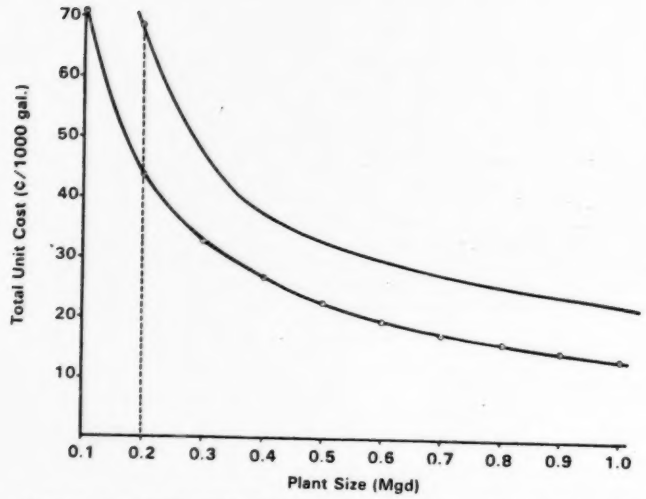

FIGURE 4. TOTAL UNIT TREATMENT COST FOR PACKAGE SYSTEMS.

1. Operation and Maintenance - Regionalization will provide for more comprehensive supervision and day-to-day management.

2. Planning and Design - Regionalization will allow for optimum planning of the water supply system particularly where the original individual systems are interconnected or could be readily interconnected.

3. Financing - A more uniform rate base and better financing because the cost of service will be distributed over a larger geographical area.

4. Government - Regionalization will assist the state regulatory agencies by reducing the number of management organizations needed to monitor water quality.

Problems with Regionalization

According to the AWWA Committee the problems associated with regionalization fall into the following catagories:

1. Public Attitude and Government - A community may be opposed to loss of control of its water system income which may be diverted to a regional general fund.

2. Inequities and Financing - Some participating municipalities may be concerned about loss of water sales revenue used for other general purpose needs.

Dan Okun, one of the outspoken advocates for regionalization has studied the regionalization process in England and Wales.[22] According to Okun, England and Wales now have the most efficient program of water management in the world. In the English model regional water authorities are responsible for the planning construction management, operation, and financing for all water based activities for 50 million people in England and Wales. Okun feels that this model could be adapted in the United States at the State level and cites several examples in which States have taken the lead in providing the mechanism for establishing regional water supplies.

One possible barrier to development of regional water systems in the U. S. in that historically, treated water has been provided by municipal governments. Clemens suggested the following reasons for this arrangement.[8]

1. Water treatment and supply is a relatively simple operation that can easily be carried out on a small scale.

2. Over the years, few changes, have occurred in water treatment technology to make the process more difficult or expensive to provide on a local level.

3. Treated water can be supplied by municipalities as a joint service with fire protection.

4. Treated water supply involves the public health, and as such it is generally viewed as the function of government.

5. Significant scale economies are lacking at the local level.

6. The private sector has failed to enter the market in many cases.

The Safe Drinking Water Act, along with other environmental legislation, encourages the development of regional systems for managing water supplies. Regionalization has great appeal to regulatory groups because it reduces the number of individual entities with which they must work.[15] Table 4 demonstrates that small systems tend to have more quality control problems than do large systems. Quality control problems can often be solved effectively in a regional context. Another possibility involves the centralization of purchasing maintenance, and various management support items. A common argument is that regional systems hydraulically interconnected exhibit economies of scale, thereby minimizing costs to the consumer. The following section examines some of these issues in more detail.

Hydraulically Interconnected Systems

The economies of scale argument holds for a limited set of circumstances, as can be demonstrated by the following data. Figure 5 shows unit costs of water treatment, uncorrected for inflation, for the Fairfax County Water Authority (Virginia) and for four other utilities over a 10 year period.

The Fairfax County Water Authority was developed by acquiring individual water service areas around the original Alexandra Water Company and, as such, has become a regional water supply utility.[4] As the Fairfax utility has grown the unit costs have decreased. These data support an economies of scale argument. Compared to the other stable utilities, the unit costs for the Fairfax Authority continuously declined between years 1 and 5, the periods of maximum growth.

On the other hand, research indicates that limitations to the economies of scale associated with regionalization may exist. The following section deals with an analytic attempt to analyze the cost trade-off between a central plant and decentralized transmission components of a utility.[6]

Economics of Regionalization

In order to completely understand the costs associated with water supply, it is important to be able to properly analyze the various cost functions that make up the water supply system. Physically, it is possible to separate the water supply system into three components. The first is the treatment plant, the second is the transmission and distribution system, and the third is management or support services.[4] Each of these components has a different cost function. The unit costs associated with treatment facilities are usually assumed to decrease as the quantity of service increases. The transmission and distribution system (the transportation costs of water) are more

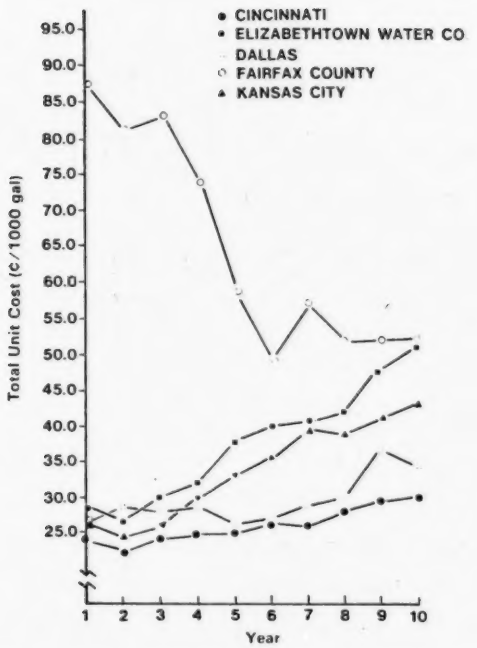

FIGURE 5. TOTAL UNIT COST FOR FIVE UTILITIES.

directly affected by the characteristics of the area being served. As pointed out by Dajani and Gemmell, "Economies of scale may be offset by diseconomies of dispersion, agglomeration or spatial arrangement, and pattern".[9]

A simple argument confirms the reasonableness of the above statement. As previously defined, economies of scale imply decreasing marginal costs with increasing values of the variable in question, or more specifically in the model $C = a\,Q^b$, as long as $b<1$ economies of scale exist (there are incentivies to overbuilding). Analysis has found that not all cost centers exhibit economies of scale (Table 10), especially acquisition.[4]

Also support services (overhead) show low economies of scale, results that make the neglect of overhead costs in the regionalization planning problem reasonable. Treatment costs definitely present high economies of scale, a fact confirmed by several investigators.[12,14,18] However, transmission and distribution again have low economies of scale based on the flow component in Table 10. The above results could lead to the conclusion that the economies of scale are concentrated in treatment plants. This is partially true, but the results are distorted by considering only flow as the factor affecting costs.

Some insight can be gained by the following analysis: consider that a pipeline conveys water between two sections, at a rate of Q, m^3/s. assuming that the head loss in the extension L of this pipeline is H, the diameter is given by:

$$D = k\,Q^{.38}\left(\frac{L}{H}\right)^{0.205} \quad \text{(Hazen-Williams formula)} \tag{6}$$

Capital costs of pipelines are expressed by:

$$C_m = 2.16\,D^{1.2} \tag{7}$$

where

C_m = construction cost in dollars per mile

D = pipe diameter, inches

The total construction cost, C, of the pipeline with length L is:

$$C = 2.16\,LD^{1.2}$$

and using the above expression for D

$$C = KQ^{0.46}\,\frac{L^{1.25}}{H^{0.25}} \tag{8}$$

TABLE 10. OPERATING AND MAINTENANCE AND CAPITAL COSTS FOR ALL UTILITIES

Item (1)	Operating Cost $C = aQ^b e^{st}$ a (2)	b (3)	s (4)	r^2 (5)	Capital Cost* $C = cQ^b e^{st}$ a (6)	b (7)	s (8)	r^2 (9)
Acquisition	1.4	1.23	0.043	0.64	2×10^{-3}	2.94	0.000	0.67
Treatment	2,379.1	0.52	0.063	0.56	32.8	0.82	0.066	0.40
Transmission & Distribution	211.0	0.82	0.052	0.92	178.0	0.89	0.036	0.86
Support Services	78.43	0.95	0.073	0.95	24.35	0.88	0.044	0.66
Total	360.4	0.91	0.056	0.93	193.8	0.91	0.043	0.86

*Capital cost in this case is reported as annual depreciation in dollars/yr.

NOTE: t = relative time, starting with year 1 as the first year of data (1965):

Q = revenue-producing water in millions of gallons per year:

C = annual cost in dollars per year.

SOURCE: Clark, R., "Water Supply: Selected Case Studies", ASCE, February, 1979.

where K is a constant. It is very clear from the above expression that strong economies of scale exist in the Q component and disconomies exist in the L component. For a utility which is expanding (increasing L) at a rate faster then it is increasing pumpage (increasing Q) transmission-distribution costs will not exhibit diseconomies of scale. In a utility in which over capacity exists (increasing Q, relative to L) the transmission-distribution systems will exhibit economies of scale.

Assume now that a pumping station is necessary to convey water in the pipeline. The energy spent in a given period in this pumping station can be expressed by:

$$E = \beta\, Q\, H \tag{9}$$

where

β = constant for the case

$H = H_G + H_L$, with H_G the hydrostatic head and H_L the head loss. The head loss can be expressed by (Hazen and Williams):

$$H_L = \frac{Q^{1.85}}{D^{4.87}}\, L \tag{10}$$

and the energy:

$$E = \beta Q\left(H_G + \frac{Q^{1.85}}{D^{4.87}} L\right) \tag{11}$$

assuming that costs of energy are given by a linear relation:

$$C_E = aE \tag{12}$$

the operating cost component given by energy is

$$C_E = a\,\beta\left(H_G Q + \frac{Q^{2.85}}{D^{4.87}} L\right) \tag{13}$$

Based on equation (13) no economies of scale exist on either Q or L. Equation (13) combined with equation (2) shows the inevitable loss of economies of scale beyond a certain system size.

Development of Cost Equations

In this section the cost equations for a regional water utility will be developed. Operating and capital costs are defined as follows. The operating costs were categorized as follows: (1) Support services, and all of those expenditures that do not relate specifically to the production of water; (2) purification, including all of the costs for

pumping water to the consumer; and (3) transmission and distribution, including the costs of transmitting and distributing water to the consumer.[4] Laboratory personnel cost, e.g., are included in the purification activity, but the management costs associated with the purification or treatment division are included in the support services activity. Capital costs are defined as the depreciated cost of plant-in-service plus historical interest paid on any borrowing mechanism. This definition of capital cost will tend to understate the current value of plant-in-service for a utility but can easily be collected on a standardized basis and was therefore used in this study. All unit cost analysis was based on revenue-producing water rather than on total water pumped.

Cost Functions

Separate equations will be presented for management or support services costs and for the acquisition-treatment and transmission-distribution costs associated with the water utility. The cost analysis will include both management and hardware or acquisition-treatment and transmission-distribution costs.

Support Services Costs

Results from a series of utility case studies show that the management function for utilities exhibits economies of scale, as shown by the following equations:[4]

$$SP_O = 226\ Q^{0.95} \tag{14}$$

$$SP_C = 5\ Q^{1.06} \tag{15}$$

where

SP_O = the operating and maintenance cost of support services or management in dollars per year; and Q = revenue-producing water, in millions of gallons per year; SP_C = the capital cost of support services or management, in dollars per year. Equations (14) and (15) will be used in the analysis to represent management costs for the utility.

Water Delivery Costs

A mathematical model for the total cost of water supply and distribution (excluding support services costs) was developed, based on a series of assumptions.[6] It was assumed that a total cost equation could be formulated as follows:

$$C_{TOT} = TQ^a + BQ^b \tag{16}$$

in which C_{TOT} = annual cost for water supply, in millions of dollars per year; Q = revenue-producing water pumped by the utility, in millions of gallons per year and T, B, a, and b = constants.

Equation (16) combines the total annual cost of each component to get total annual cost for the system, but maintains the separability of the two relationships. The first term represents the cost of treatment and the second term the distribution cost.

Water usage has been related to numerous independent variables, such as price, income, population, lot size, and rainfall. In this case, water usage is calculated for a given area in the delivery system by multiplying population density by area of service and water use per capita.

This relationship was represented by

$$Q = CP_dA \tag{17}$$

in which Q = total water use for a given area, in millions of gallons (cubic meters); C = per capita use per year, millions of gallons (cubic meters); P_d = population density, in people per square mile (square meter); and A = the area over which usage is to be determined, in people per square mile (square meter).

Several studies have provided strong evidence that population density falls off fairly smoothly and at a decreasing rate as one moves away from the city center.[20] It was found that the negative exponential function provided a good approximation to the decreasing population densities in the case study service area. In general, this relationship may be written as

$$P_d = Ke^{-\lambda r} \tag{18}$$

in which P_d = the density r miles (meters from the center; e = the base of the natural logarithm; and K and λ = parameters to be estimated from the data. The value K is the measure of density at the city center; and λ, which is positive, is a measure of rate at which density declines with distance. If λ is large, then it follows that the density falls off rapidly; if it is small, density falls off slowly.

By making the appropriate substitution, and integrating equation 18 over the service area, the following unit cost equation was developed:[6]

$$TUC = \frac{T[\theta CK[1 - e^{-\lambda d}(1 + \lambda d)]^{\alpha-1}]}{\lambda^2} + \frac{B(CK)^{-1}[1 - e^{\beta\lambda d}(1 - \beta\lambda d)]}{\lambda^2} \Big/ [1 - e^{-\lambda d}(1 + \lambda d)] \tag{19}$$

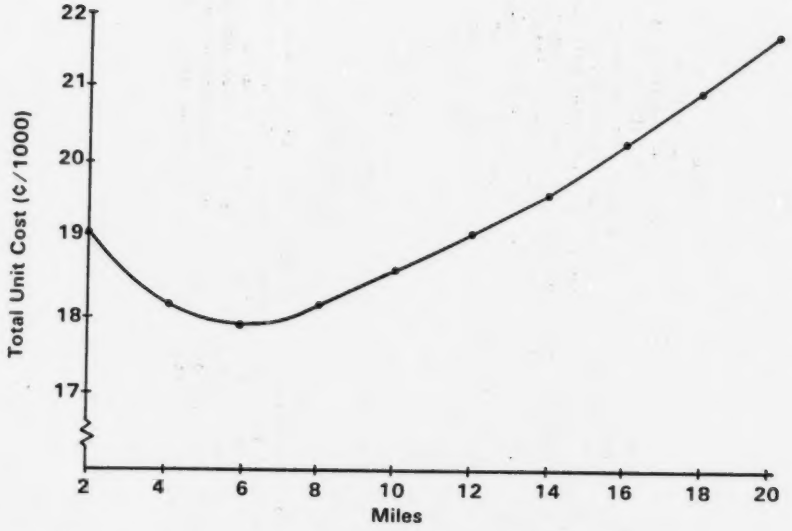

FIGURE 6. UNIT COST WITH DISTANCE USING 150 GAL/CAP/DAY.

in which TUC = total unit cost, in dollars per million gallons (dollars per cubic meter); and θ = limits of integration reflecting the geometry of the utility service area.

. Equation (19) can be used to estimate the cost trade offs associated with regional water utility management.

Figure 6 illustrates a typical cost curve for a utility. As can be seen the utility in its current configuration has reached the limits of system expansion before unit costs begin to increase.

SUMMARY AND CONCLUSIONS

Regionalization, whether a coordinated management arrangement or a physically interconnected system has many advantages. Regionalization offers the possibility of achieving lower unit costs through increased system size, greater reliability of supply through multiple source availability, and higher drinking water quality. Increased water quality requirements and associated increases in costs will no doubt increase interest in regional water utilities particularly among small systems. Many investigators have outlined the benefits that have been achieved through regionalization in this country and outside the U.S. Economies of scale can be achieved through system consolidation as demonstrated by the growth of the Fairfax County Water Authority. However adoption of the regional concept should be done with the understanding that there are also limits to the benefits achieved. The regional cost equations illustrate the limitations of scale for system growth. Regionalization therefore also has its negative aspects. Hopefully this analysis will be used to enhance the most efficient growth of regional water systems.

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References

1. Clark, Robert M., "Small Water Systems: Role of Technology" Journal of the Environmental Engineering Division, ASCE, Vol. 106, No. EE1, Proc. Paper 15181, Febrauary, 1980 pp. 19-35.

2. Clark, R. M., "The Safe Drinking Water Act: Its Implications for Planning", Reprinted from, Municipal Water Systems - "The Challange for Urban Resource Management," eds., David Holtz and Scott Sebastian, Holcomb Research Institute, Indiana University Press, Bloomington, Ind., 1978.

3. Clark, R. M., "Water Supply Regionalization: A Critical Evaluation", Journal of the Water Resources Planning and Management Division, ASCE, New York, September, 1979.

4. Clark, R. M., Gillean, J. I., and Adams, W. K., The Cost of Water Supply and Water Utility Management, Vol. I & II, Water Supply Research Division, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio, EPA-600/5-77-015a & b, Nov. 1977.

5. Clark, R. M., and Goddard, H. C., "Cost and Quality of Water Supply", Journal of the American Water Works Association, Vol. 69, No. 1, January, 1977.

6. Clark, Robert M., and Stevie, Richard G., "A Water Supply Cost Model Incorporating Spatial Variables", Land Economics, Vol. 57, No. 1, February 1981, pp. 18-32.

7. Clark, R. M., and R. G. Stevie, 1978. "Meeting the Drinking Water Standards: The Price of Regulation." Safe Drinking Water: Current and Future Problems, ed., Clifford C. Russell, Resources for the Future, Research Paper 12, 1978, pp. 172-217.

8. Clemens, E. I., 1950. Economics and Public Utilities, Appleton-Century Crofts, New York, New York.

9. Dajani, J. S., and Gammel, R. S., "Economic Guidelines for Public Utility Planning", Journal of the Urban Planning and Development Division, ASCE, Vol. 99, No. UP2m Oric, Paper 9977, Sept. 1976, pp. 171-182.

10. Draper, N., and Smith, H. Applied Regression Analysis, John Wiley & Sons, New York, New York (1967).

11. Greenberg, M.R., and R. M. Horton, 1976. Water Supply Planning: A Case Study and Systems Analysis - Rutgers Center for Urban Policy Research, New Brunswick, New Jersey.

12. Grossman, D. S. Capacity Expansion for Water and Wastewater Services, MIT, Department of Civil Engineering, PhD Thesis, January 1977.

13. Gumerman, R.C., Culp, R. L., and Hanson, J. D., Estimating Costs for Water Treatment As A Function of Size and Treatment Efficiency, Drinking Water Research Division Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH, EPA-600/2-78-182, Aug. 1978.

14. Hinomoto, H. "Dynamic Programming of Capacity Expansion of Municipal Water Treatment Systems", Water Resources Research, Vol. 8, No. 5, October 1972.

15. Hooks, Donald L., Treatment Water Demand and The Economics of Regionalization; Vol. 2 - Economics of Regionalization: The Electric Power Example, EPA-600/280-163, MERL, USEPA, Cincinnati, Ohio 45268, August 1980.

16. Koelzer, P. E., and Bigler, A. B., Policies and Organizations for Urban Water Management, Water Resources Publications, Fort Collins, Colorado, 1975.

17. Maddox, Franklin D., Water Supply and Consumer Costs, Cincinnati Standard Metropolitan Statistical Area, unpublished report for the Bureau of Water Hygiene (Mar. 5, 1970).

18. Manne, A. S. editor, Investments for Capacity Expansion Size, Location and Time Phasing, MIT Press, Cambridge, MA, 1967.

19. McCabe, L. J., Symons, J. M., Lee, R. D., and Robeck, G. G., "Survey of Community Water Supply Systems" Journal of the American Water Works Association, Vol. 62, No. 11, 1970, pp. 670-686.

20. Mills, E. S., Studies in the Structure of the Urban Economy, The Johns Hopkins Press for Resources for the Future, Baltimore, Md., 1972.

21. National Interim Primary Drinking Water Regulations, U.S. Environmental Protection Agency, Office of Water Supply, EPA-570-19-76-003.

22. Okun, Daniel A. "State Initiatives for Regionalization" Journal of the American Water Works Association, Vol. 73, No. 5, May 1981, pp. 243-245.

23. Orlob, G. T., and Lindorf, M. R., "Cost of Water Treatment in California", Journal of the American Water Works Association, Vol. 50, Jan. 1958, pp. 45-55.

24. Public Law 93-523, Safe Drinking Water Act, 93rd Congress, Washingon, D.C., 16 December 1974.

25. Ramos, Fabio, Kilgore, Roger, Herman, Barbara, Marks, David, Regionalization of Urban Water Supply Systems: Capacity Expansion in Networks, First Year Progress Report for the U.S. Environmental Protection Agency, unpublished.

26. Regionalization of Water Utilities: Needs and Issues, a Committee Report, Journal of the American Water Works Association, Vol. 1, No. 12, Dec. 1979, pp. 698-701.

27. Stevie, Richard G., and Clark, Robert M. "Costs for Small Systems to Meet the National Interim Drinking Water Regulations", Journal of the American Water Works Association, Vol. 74, No. 1, January 1982, pp. 13-17.

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